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(45) **Date of Patent:** Jun. 2, 2015

- (56)
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| 7,091,475 | B2 * | 8/2006 | Tobiason | 250/231.16 |
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Primary Examiner — Tony Ko

(57) **ABSTRACT**

- A transmissive optical encoder is disclosed. The transmissive optical encoder includes a detector, a code wheel, and an emitter. The detector includes an aperture through the detector. The aperture is configured to receive a rotary shaft of a motor. The code wheel is coupled to the rotary shaft of the motor. Rotation of the rotary shaft results in corresponding rotation of the code wheel. The emitter is configured to emit a light signal through the code wheel toward the detector. Rotation of the code wheel results in modulation of the light signal at the detector. Embodiments of the transmissive optical encoder consume relatively little space and facilitate alignment of the emitter and detector.

- 16 Claims, 10 Drawing Sheets**

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- Fig. 1 is a cross-sectional view of a motor assembly. The assembly includes a stator assembly (60, 62) at the top, a rotor assembly (52, 54) in the middle, and a base assembly (16, 68, 64, 66) at the bottom. Arrows indicate the flow of magnetic flux or air from the stator, through the rotor, and into the base.

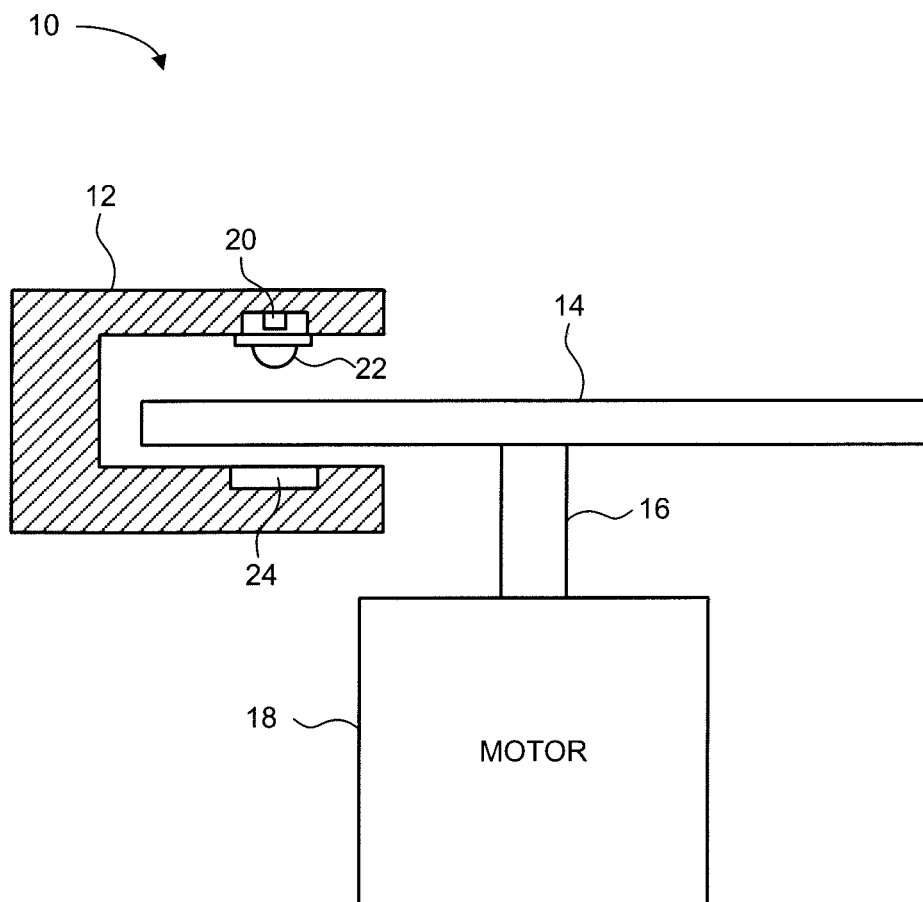


FIG. 1 (Prior Art)

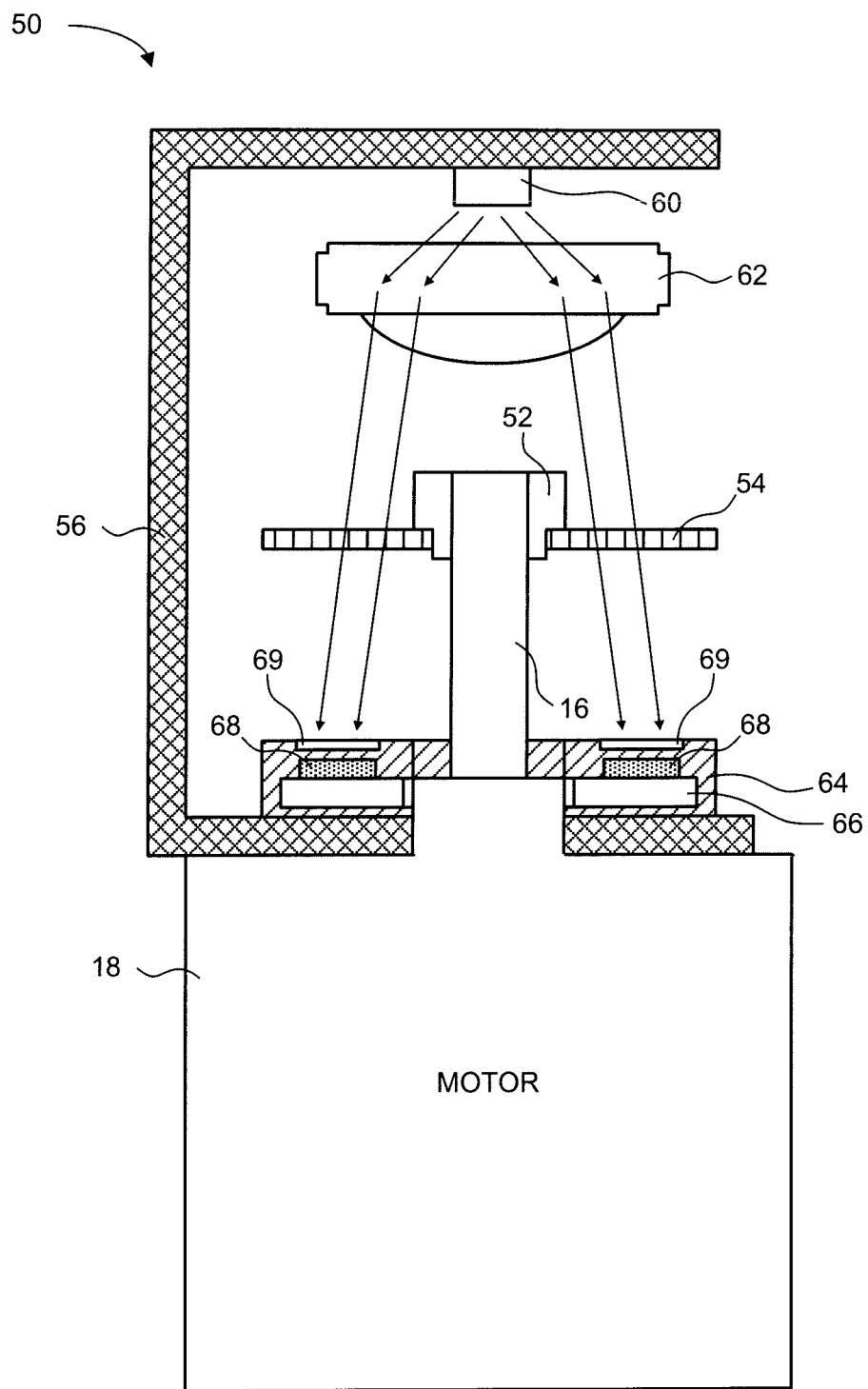


FIG. 2

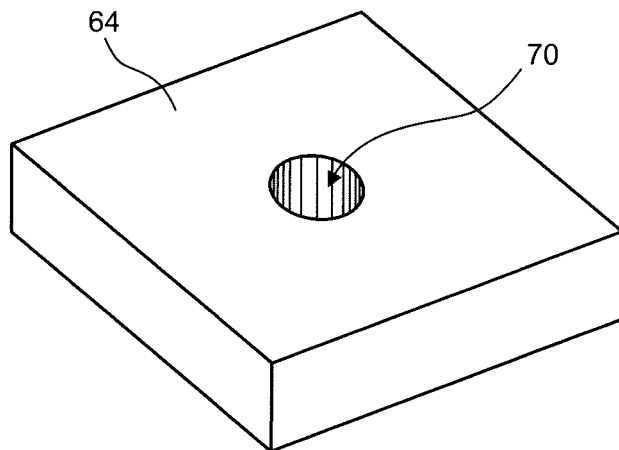


FIG. 3A

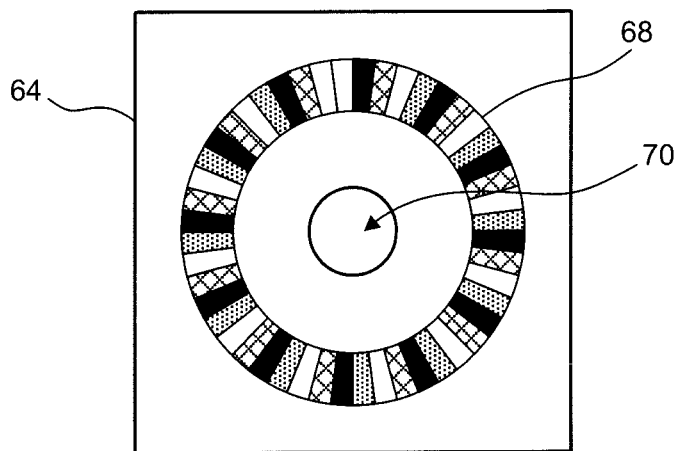


FIG. 3B

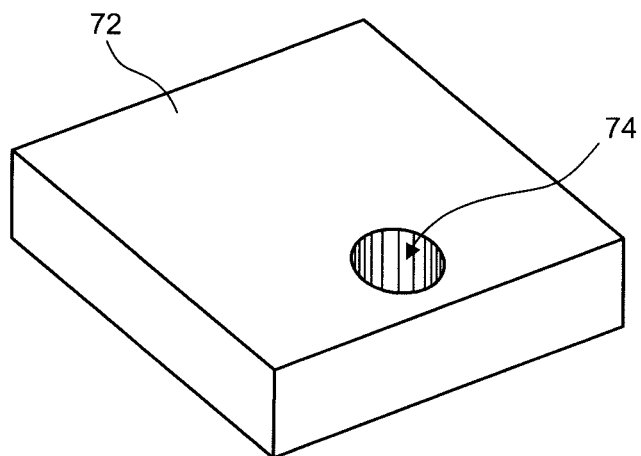


FIG. 4

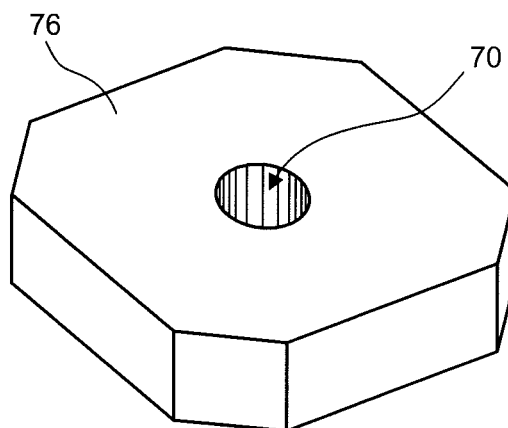


FIG. 5

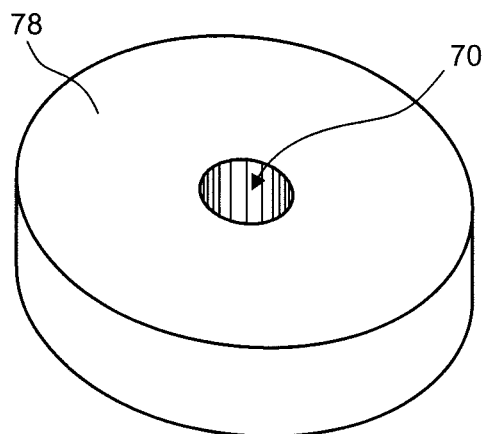


FIG. 6

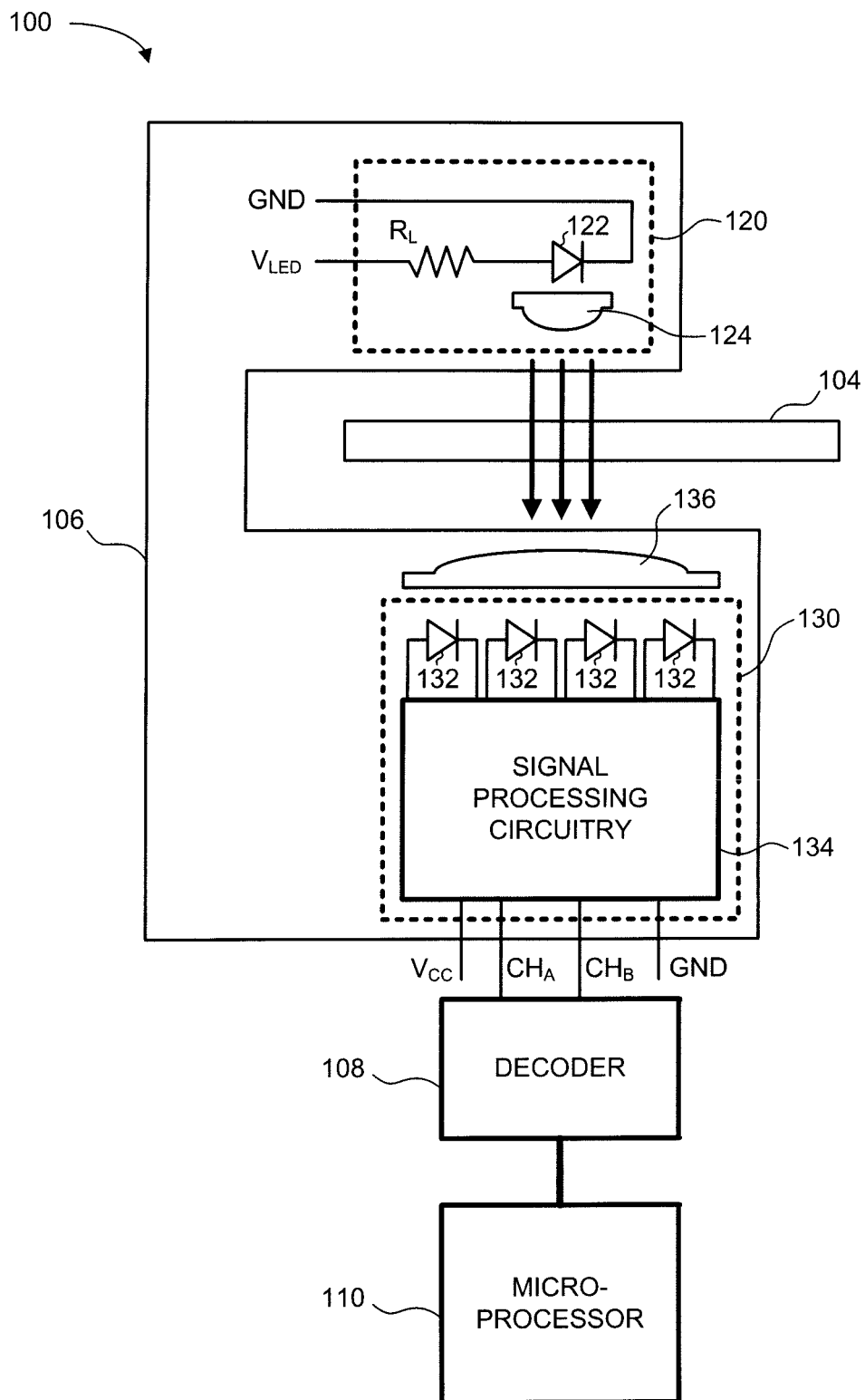


FIG. 7

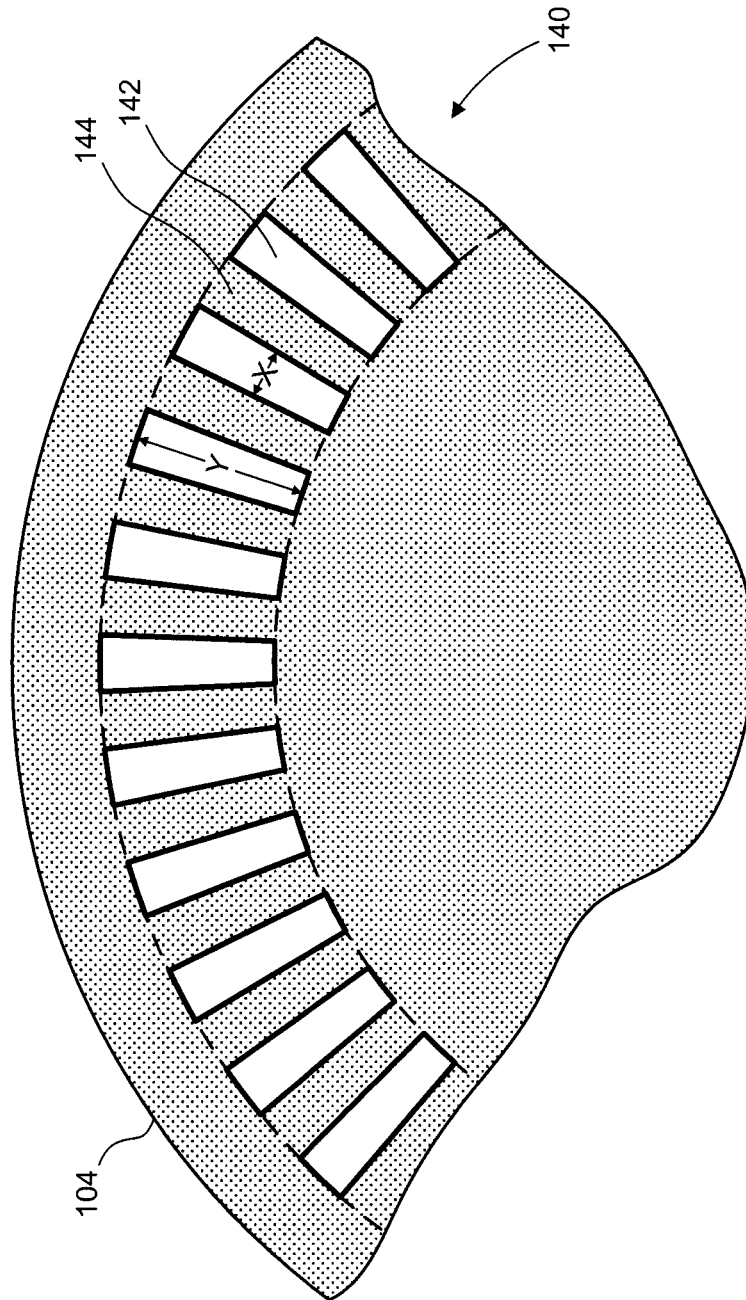


FIG. 8

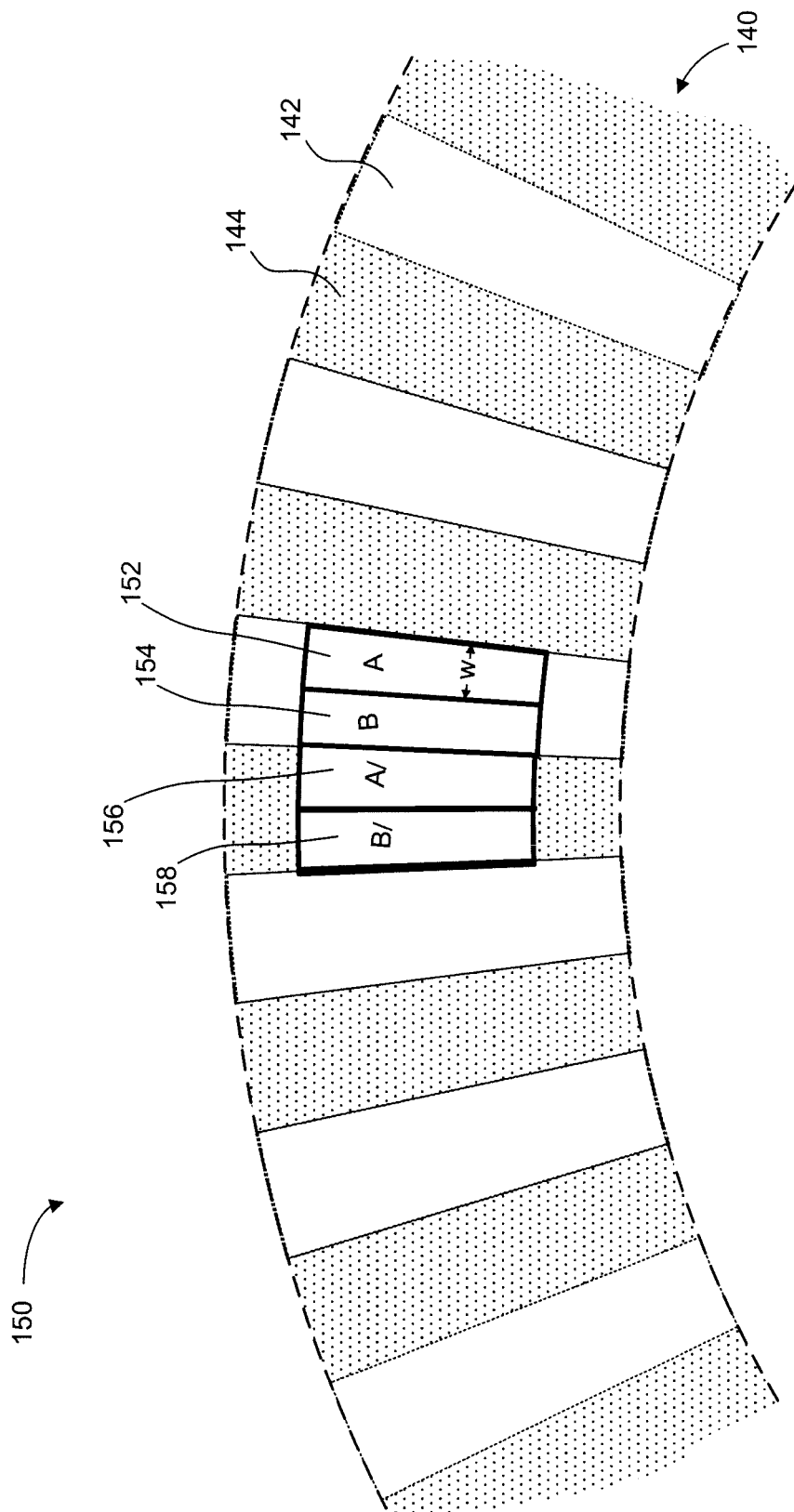


FIG. 9

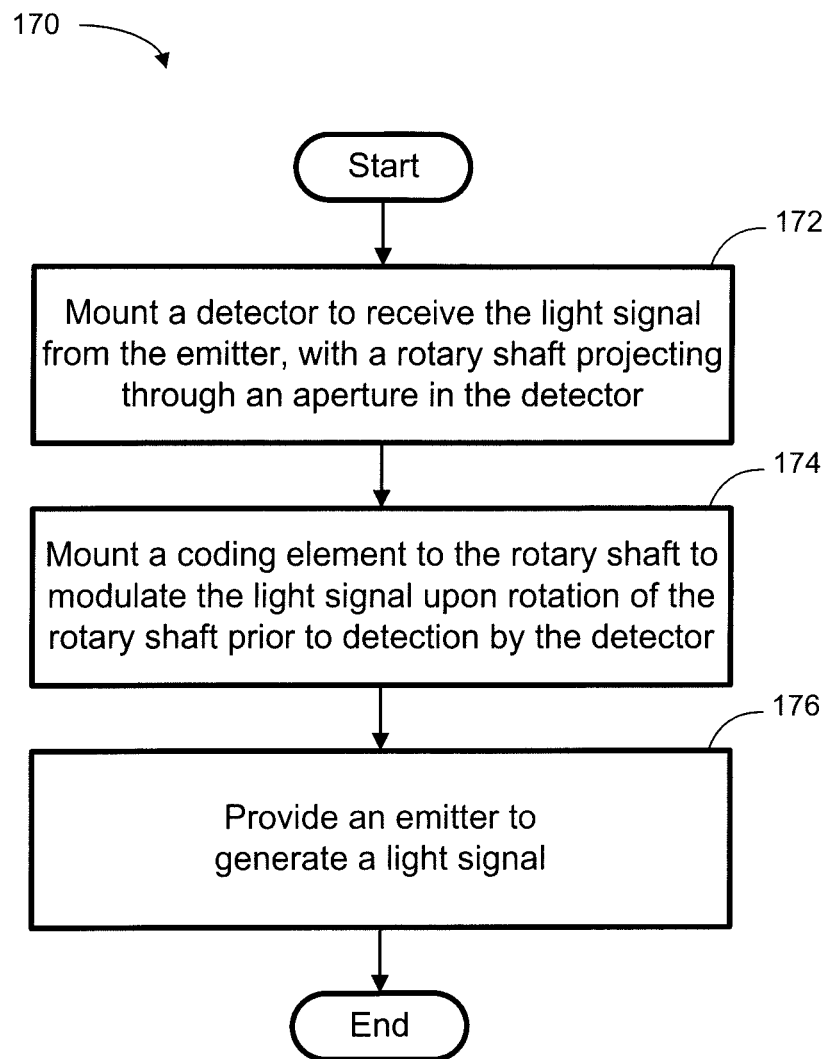


FIG. 10

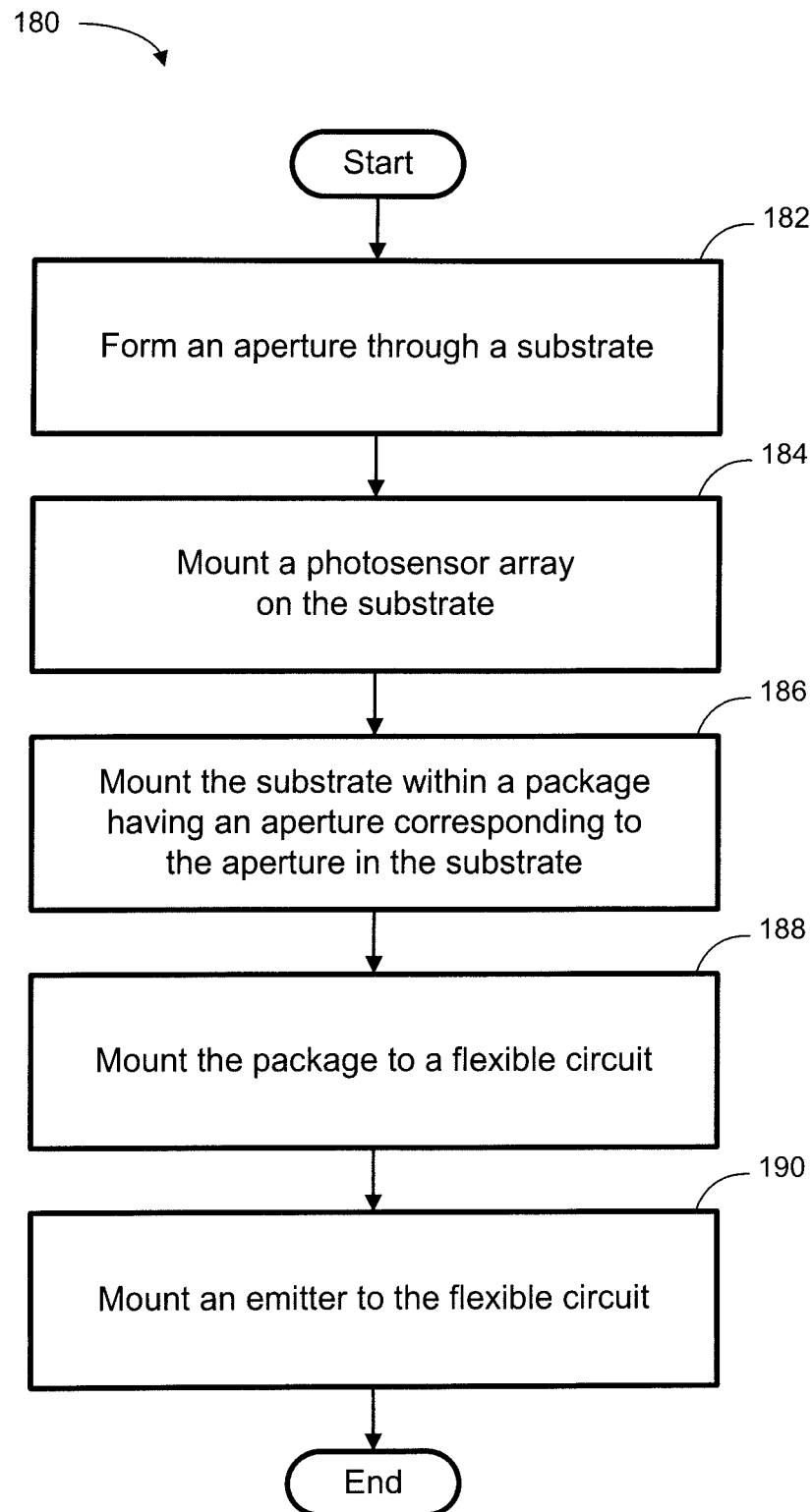


FIG. 11

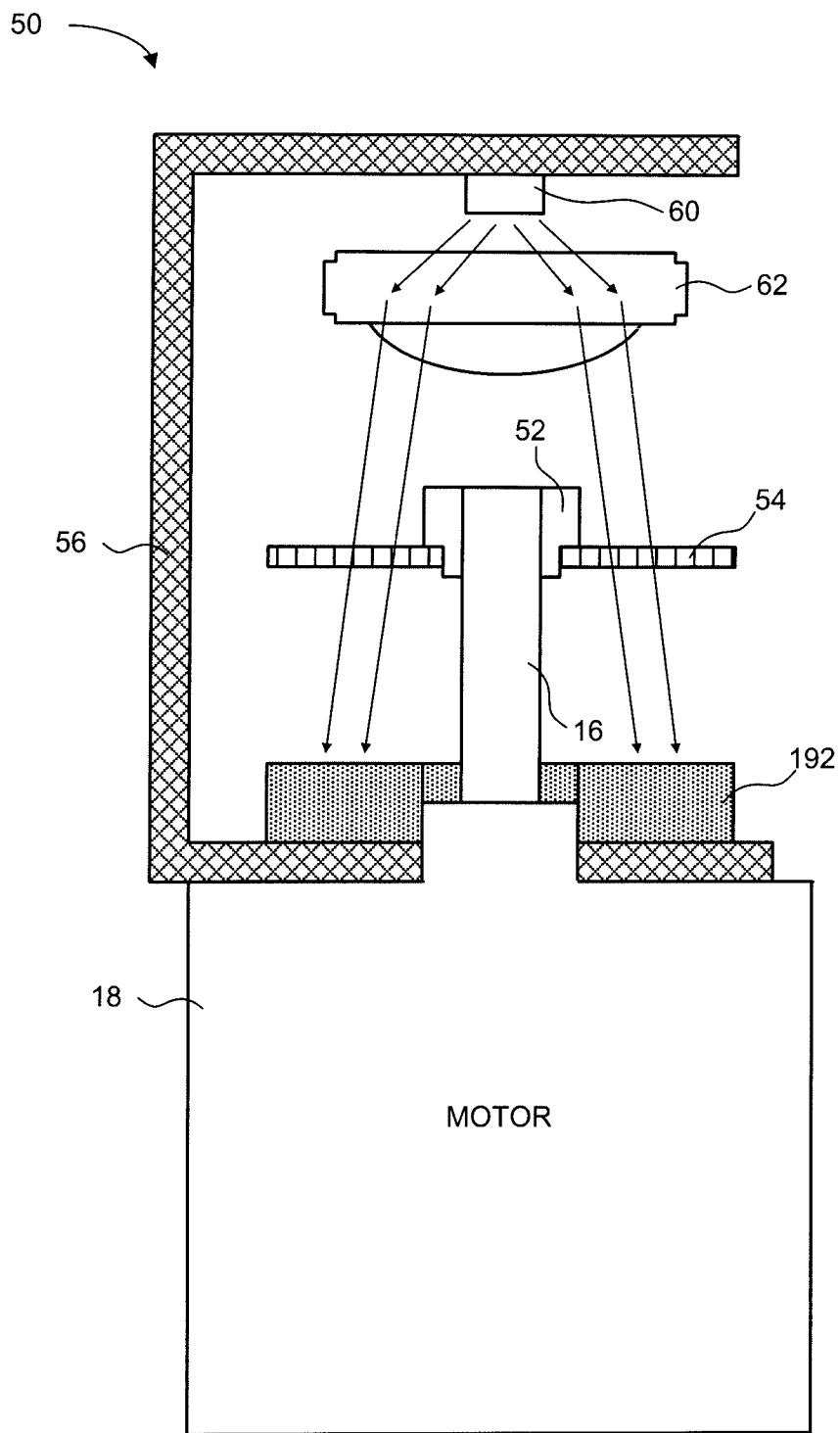


FIG. 12

1

SHAFT-MOUNTED DETECTOR FOR OPTICAL ENCODER

CROSS REFERENCE TO RELATED APPLICATIONS

This is a divisional of copending application Ser. No. 11/868,508, filed Oct. 7, 2007, the entire disclosure of which is incorporated into this application by reference.

BACKGROUND OF THE INVENTION

Optical encoders are used to monitor the motion of, for example, a rotary shaft such as a crank shaft. Optical encoders can monitor the motion of a shaft in terms of position and/or number of revolutions of the shaft. Optical encoders typically use a code wheel attached to the shaft to modulate light as the shaft and the code wheel rotate. In a transmissive code wheel, the light is modulated as it passes through transmissive sections of a track on the code wheel. The transmissive sections are separated by non-transmissive sections. In a reflective code wheel, the light is modulated as it is reflected off of reflective sections of the track on the code wheel. The reflective sections are separated by non-reflective sections. As the light is modulated in response to the rotation of the code wheel, a stream of electrical signals is generated by a photosensor array that receives the modulated light. The electrical signals are used, for example, to determine the position and/or number of revolutions of the shaft.

FIG. 1 illustrates a conventional transmissive optical encoder system 10. The optical encoder system 10 includes an encoder 12 and a transmissive code wheel 14. The code wheel 14 is coupled to a rotary shaft 16 of a motor 18. The encoder 12 includes a light source 20, a collimating lens 22, and a detector 24. Together, the light source 20 and the collimating lens 22 also may be referred to as an emitter. The light source 20 emits light, which is collimated by the collimating lens 22 and is modulated as it passes through the transmissive sections of the code wheel 14. The detector 24 includes a photosensor array such as an array of photodiodes which detects the modulated light. Typically, the photosensor array has a resolution that is equal to the resolution of the coding element.

One disadvantage of conventional transmissive optical encoders, compared to conventional reflective optical encoders, is that the placement of the emitter 20 and the detector 24 on opposite sides of the code wheel 14 consumes more space, making the conventional transmissive optical encoder 12 relatively large. Also, misalignment of the emitter 20 and/or the detector 24 with the code wheel 14 or with each other degrades the performance of conventional transmissive optical encoders 12.

SUMMARY OF THE INVENTION

Embodiments of a transmissive optical encoder are described. In one embodiment, the transmissive optical encoder includes a detector, a code wheel, and an emitter. The detector includes an aperture through the detector. The aperture is configured to receive a rotary shaft of a motor. The code wheel is coupled to the rotary shaft of the motor. Rotation of the rotary shaft results in corresponding rotation of the code wheel. The emitter is configured to emit a light signal through the code wheel toward the detector. Rotation of the code wheel results in modulation of the light signal at the detector. Embodiments of the transmissive optical encoder consume

2

relatively little space and facilitate alignment of the emitter and detector. Other embodiments of the transmissive optical encoder are also described.

Embodiments of a detector of a transmissive optical encoder are also described. In one embodiment, the detector includes a substrate and a photosensor array. The substrate includes an aperture through the substrate. The aperture is configured to receive a rotary shaft of a motor. The photosensor array is coupled to the substrate. The photosensor array is located on the substrate at a position to receive a modulated light signal from an emitter through a coding element coupled to the rotary shaft. Other embodiments of the detector are also described.

Embodiments of a method are also described. In one embodiment, the method is a method for method for assembling transmissive optical encoder system. The method includes mounting a detector comprising a photosensor array on a rotary shaft of a motor. The rotary motor shaft projects through an aperture in the detector. The method also includes mounting a coding element to the rotary shaft to modulate a light signal upon rotation of the rotary shaft. The method also includes mounting an emitter relative to the coding element to generate the light signal and to direct the light signal toward the coding element. The detector is located to detect the modulated light signal. Other embodiments of the method are also described.

Other aspects and advantages of embodiments of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrated by way of example of the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a conventional transmissive optical encoder system.

FIG. 2 depicts a schematic block diagram of one embodiment of a transmissive optical encoding system mounted directly on a shaft of a motor.

FIG. 3A depicts a schematic perspective view of one embodiment of a rectangular detector for use in the optical encoder of FIG. 2.

FIG. 3B depicts a schematic top view of one embodiment of a rectangular detector with a circular photosensor array which circumscribes the aperture that extends through the detector.

FIG. 4 depicts a schematic perspective view of another embodiment of a rectangular detector with an offset aperture for use in the optical encoder of FIG. 2.

FIG. 5 depicts a schematic perspective view of another embodiment of rectangular detector with chamfered corners for use in the optical encoder of FIG. 2.

FIG. 6 depicts a schematic perspective view of one embodiment of a circular detector for use in the optical encoder of FIG. 2.

FIG. 7 depicts a schematic circuit diagram of one embodiment of an optical encoder for use in the transmissive optical encoder system of FIG. 2.

FIG. 8 depicts a partial schematic diagram of one embodiment of a code wheel.

FIG. 9 depicts a schematic layout of one embodiment of a photosensor array relative to the code wheel track.

FIG. 10 depicts a schematic flow chart diagram of one embodiment of a method for assembling the transmissive optical encoder system of FIG. 2.

3

FIG. 11 depicts a schematic flow chart diagram of one embodiment of a method for making a detector for the optical encoder of FIG. 2.

FIG. 12 depicts a schematic block diagram of another embodiment of the transmissive optical encoding system of FIG. 2.

Throughout the description, similar reference numbers may be used to identify similar elements.

DETAILED DESCRIPTION

FIG. 2 depicts a schematic block diagram of one embodiment of a transmissive optical encoding system 50 mounted directly on a shaft 16 of a motor 18. The illustrated transmissive optical encoding system 50 includes a code wheel mounting device 52 to mount a code wheel 54 to the shaft 16 of the motor 18. Any type of conventional code wheel mounting device 52 may be used. In some embodiments, the code wheel 54 may be any type of conventional transmissive code wheel 54. Some exemplary code wheels 54 are describe in U.S. Pat. Nos. 4,451,731, 4,691,101, and 5,241,172, which are incorporated by reference herein. Other code wheels 54 also may be used. At least one embodiment of a code wheel 54 is described in more detail below, referring to FIG. 8.

The illustrated transmissive optical encoding system 50 also includes a flexible circuit 56. An emitter 60 is mounted to the flexible circuit 56 at a location that allows the emitter 60 to emit a light signal (shown as arrows) toward the motor 18 through the code wheel 54. Other embodiments may use a rigid circuit or other connection in place of the flexible circuit 56 shown and described herein. For example, wires may be used in place of the flexible circuit 56. Some embodiments also include a collimating lens 62 to collimate the light from the emitter 60 prior to transmission through the code wheel 54. Various types of emitters 60 and collimating lenses 62 are known.

The illustrated optical encoding system 50 also includes a detector 64. The detector 64 is mounted to the flexible circuit 56 at a location to receive the light signal from the emitter 60, after the light signal passes through the code wheel 54. Exemplary embodiments of the detector 64 include integrated circuit (IC) dice and IC packages. Although various types of detectors 64 may be used, the depicted detector 64 includes a substrate 66 and a photosensor array 68. Some embodiments of the detector 64 also include a package to enclose, or house, the substrate 66 and the photosensor array 68. In one embodiment, the photosensor array 68 is circular so that it circumscribes the shaft 16 of the motor 18. One example of a circular photosensor array 68 is shown in FIG. 3B and described in more detail below. Other embodiments of photosensor arrays also may be implemented.

In order for the light to reach the photosensor array 68 within the package, the detector 64 may include a substantially transmissive window 69 that is aligned with the photosensor array 68. For example, if a circular photosensor array 68 is implemented, then the window may be circular 69 to substantially correspond to the circular photosensor array 68. In this way, the photosensor array 68 is able to receive the light from the emitter 60 that transmits through the code wheel 54. In an alternative embodiment, the package may include a cutaway window, instead of the transmissive window 69, so that there is no structure to impede or otherwise modify the path of the light signal from the code wheel 54. In another embodiment, the photosensor array 68 may be approximately flush with the package at the incident surface of the detector 64. In another embodiment, the photosensor array 68 may extend out of the package of the detector 64. In

4

another embodiment, the detector 64 may be implemented without a package, so there is no need for a transmissive window 69 or other portion to allow the light signal to be incident on the photosensor array 68.

Regardless of the type of detector technology implemented, the detector 64 includes an aperture, or hole, that extends through the detector 64. In other words, there is an aperture through the substrate 66 and, where a package is used to house the substrate 66, there is a corresponding aperture through the package. The presence of the aperture through the detector 64 allows the rotary shaft 16 of the motor 18 to extend through the detector 64. In other words, the detector 64 is mounted eccentric to the motor shaft 16 of the motor 18.

In one embodiment, the aperture approximately corresponds in size with the motor boss (the plastic structure that surrounds the motor shaft 16 as it protrudes from the housing of the motor 18). This embodiment maintains a separation between the shaft 16 and the detector 64 so that the shaft 16 does not create friction on the detector 64 as the shaft 16 rotates. Alternatively, the detector 64 may be mounted to the housing of the motor 18 using a centering jig to maintain the separation between the shaft 16 and the detector 64.

The size (i.e. diameter) of the aperture may vary depending on the implementation for which the detector 64 is designed. In some embodiments, the aperture may be just large enough, within a measurable tolerance, to allow the shaft 16 to extend through the detector 64. In other embodiments, the aperture may be sized, within a tolerance, to fit around a portion of the motor housing near the shaft 16. Where the aperture is sized to fit relatively closely to the shaft or the corresponding portion of the motor housing, the placement of the detector 64 on the shaft 16 may facilitate the proper alignment of the emitter 60 with the photosensor array 68 of the detector 64. Additionally, the aperture may facilitate alignment of the emitter 60 and/or the photosensor array 68 of the detector 64 with the code wheel 54. In other embodiments, the aperture may be substantially larger than the shaft 16 of the motor 18 to facilitate easy assembly of the transmissive optical encoding system 50.

It should also be noted that at least some embodiments of the transmissive optical encoding system 50 include a housing (not shown) for the optical encoder. In this way, the optical encoder may be protected from potentially harmful operating conditions such as dust, dirt, ink, or other particulate matter, depending on the application in which the optical encoder is implemented.

FIG. 3A depicts a schematic perspective view of one embodiment of a rectangular detector 64 for use in the optical encoder of FIG. 2. In particular, the package of the rectangular detector 64 is shown, and the substrate 66 and photosensor array 68 are mounted within the package. The illustrated rectangular detector 64 includes an aperture 70 that extends through the entire structure of the detector 64, including the substrate 66 and the package. Although the photosensor array 68 and the window 69 are not shown in FIG. 3A, FIG. 3B depicts a schematic top view of one embodiment of a rectangular detector 64 with a circular photosensor array 68 which circumscribes the aperture 70 that extends through the detector 64. In the depicted photosensor array 68 of FIG. 3B, the individual photodiodes are distinguished. Also, it should be noted that, although embodiments of an incremental encoder are shown and described herein, other embodiments of the transmissive optical encoding system 50 may implement other types of encoders, including an incremental encoder for multiple channels, a commutation encoder with multiple channels, a pseudo-absolute encoder, an absolute encoder, or

5

another type of encoder. Additional details of the functionality of the photosensor array **68** are described in more detail below with reference to FIG. 9.

Although the aperture **70** is shown with a substantially circular cross-section, other embodiments of the detector **64** may have apertures with other shapes and sizes of apertures. For example, some embodiments of the detector **64** include apertures **70** with rectangular, square, triangular, or oval cross-sections. Other embodiments of the detector include apertures **70** with non-canonical shapes, for example, to conform to the shape of an extended portion of the motor housing. Additionally, other embodiments include more than one aperture, in order to accommodate multiple structures (e.g., the shaft **16**) extending through the detector **64**.

FIG. 4 depicts a schematic perspective view of another embodiment of a rectangular detector **72** with an offset aperture **74** for use in the optical encoder of FIG. 2. Although the shape and size of the aperture **74** is substantially similar to the shape and size of the aperture **70** of the detector **64** shown in FIG. 3, the aperture **74** is offset so that it is closer to one edge of the detector **72**. This embodiment may facilitate a simpler layout for the circuitry within the detector **72**, compared to the detector **64** of FIG. 3.

FIG. 5 depicts a schematic perspective view of another embodiment of rectangular detector **76** with chamfered corners for use in the optical encoder of FIG. 2. The corners of the rectangular detector **76** are chamfered so that the overall space consumption of the detector **76** is smaller compared to a rectangular detector of the same size without chamfered corners. Embodiments with chamfered corners may conform better to cylindrical housings of certain motors.

FIG. 6 depicts a schematic perspective view of one embodiment of a circular detector **78** for use in the optical encoder of FIG. 2. In particular, the circular detector **78** has a cylindrical shape. Like the rectangular detector **76** with chamfered corners, the circular detector **78** may conform better to cylindrical housings of certain motors. Using different shapes for different implementations may provide increased detector area in the relatively small application areas. In other words, different shapes of detectors allow the optical encoder to fit into small form factor implementations.

FIG. 7 depicts a schematic circuit diagram of one embodiment of an optical encoder **100** for use in the transmissive optical encoder system **50** of FIG. 2. The illustrated transmissive optical encoding system **100** includes a code wheel **104**, an encoder **106**, a decoder **108**, and a microprocessor **110**. The code wheel **104** is substantially similar to the code wheel **54** of FIG. 2. Although a more detailed illustration of the code wheel **104** is provided below with reference to FIG. 8, a brief explanation is provided here as context for the operation of the transmissive optical encoding system **100** shown in FIG. 7.

In general, the code wheel **104** includes a track **140** of transmissive sections **142** and non-transmissive sections **144**. An emitter **120** in the encoder **106** produces light (i.e., a light signal) that is incident on the code wheel track **140**. As the code wheel **104** is rotated, for example by a motor shaft **16**, the incident light is transmitted through the code wheel **104** by the transmissive sections **142** of the track **140**, but is not transmitted by the non-transmissive sections **144** of the track **140**. Thus, the light is transmitted through the track **140** in a modulated pattern (i.e., on-off-on-off . . .). A detector **130** in the encoder **106** detects the modulated light signal and, in response, generates one or more periodic channel signals (e.g., CH_A and CH_B). In one embodiment, these channel signals are then transmitted to the decoder **108**, which generates a count signal and transmits the count signal to the micropro-

6

cessor **110**. The microprocessor **110** uses the count signal to evaluate the movement of, for example, the motor shaft **16** or other moving part to which the code wheel **104** is coupled. Other embodiments may implement other types of code wheels **104**, such as multi-track and absolute position code wheels, as are known in the art.

In one embodiment, the encoder **106** includes the emitter **120** and the detector **130**. The emitter **120** includes a light source **122** such as a light-emitting diode (LED). For convenience, the light source **122** is described herein as an LED, although other light sources, or multiple light sources, may be implemented. In one embodiment, the LED **122** is driven by a driver signal, V_{LED} , through a current-limiting resistor, R_L . The details of such driver circuits are well-known. Some embodiments of the emitter **120** also may include a collimating lens **124** (substantially similar to the collimating lens **62** of FIG. 2) aligned with the LED **122** to direct the projected light in a particular path or pattern. For example, the collimating lens **124** may direct approximately parallel rays of light onto the code wheel track **140**.

In one embodiment, the detector **130** includes one or more photosensors **132** such as photodiodes. The photosensors **132** may be implemented, for example, in an integrated circuit (IC). For convenience, the photosensors **132** are described herein as photodiodes, although other types of photosensors **132** may be implemented. In one embodiment, the photodiodes **132** are uniquely configured to detect a specific pattern or wavelength of transmitted light. In some embodiments, several photodiodes **132** may be used to detect modulated light signals from multiple tracks **140**, including positional tracks and index tracks, or a combined position and index track. Also, the photodiodes **132** may be arranged in a pattern that corresponds to the radius and design of the code wheel **104**. The various patterns of photodiodes **132** are referred to herein as a photosensor array.

The electrical signals produced by the photodiodes **132** are processed by signal processing circuitry **134** which generates the channel signals, CH_A and CH_B . The signal processing circuitry **134** also may generate other signals, including other channel signals, complementary channel signals, or an indexing signal, which may be used to determine the rotational position or the number of rotations of the code wheel **104**.

In one embodiment, the detector **130** also includes one or more comparators (not shown) to facilitate generation of the channel signals. For example, analog signals (and their complements) from the photodiodes **132** may be converted by the comparators to transistor-transistor logic (TTL) compatible, digital output signals. In one embodiment, these output channel signals may indicate count and direction information for the modulated light signal.

Additionally, the encoder **106** may include a detector lens **136** to direct the modulated light signal toward the photodiodes **132**. In one embodiment, the detector lens **136** is mounted in front of the detector **130** for better light extraction and to ensure sufficient power delivery onto the detector **130**. Various embodiments of the detector lens **136** may be implemented, as described below.

Additional details of emitters, detectors, and optical encoders, generally, may be referenced in U.S. Pat. Nos. 4,451,731, 4,691,101, and 5,241,172, which are incorporated by reference herein.

FIG. 8 depicts a partial schematic diagram of one embodiment of a code wheel **104**. In particular, FIG. 8 illustrates a portion of a circular code wheel **104** in the shape of a disc. In some embodiments, the code wheel **104** may be in the shape of a ring, rather than a disc. The illustrated code wheel **104** includes a track **140**, which may be a circular track that is

concentric with the code wheel **104**. In one embodiment, the track **140** includes a continuous repeating pattern that goes all the way around the code wheel **104**. The depicted pattern includes alternating transmissive sections **142** and non-transmissive sections **144**, although other patterns may be implemented. In one embodiment, the transmissive sections **142** are transparent sections of the code wheel **104** or, alternatively, voids (e.g., holes) in the code wheel **104**. The non-transmissive sections **144** are, for example, opaque sections in the code wheel **104** or, alternatively, reflective sections in the code wheel **104**. In one embodiment, the surface areas corresponding to the non-transmissive sections **144** are coated with an absorptive material.

In another embodiment, a circular coding element **104** may be implemented with a spiral bar pattern, as described in U.S. Pat. No. 5,017,776, which is incorporated by reference herein. Alternatively, other light modulation patterns may be implemented on various shapes of coding elements.

As described above, rotation of the code wheel **104** and, hence, the track **140** results in modulation of the transmitted light signal at the detector **130** to measure positional changes of the code wheel **104**. Other embodiments of the code wheel **104** may include other tracks such as additional positional tracks or an index track, as are known in the art.

In the depicted embodiment, the transmissive and non-transmissive track sections **142** and **144** have the same circumferential dimensions (also referred to as the width dimension). In other words, the intermediate non-transmissive track sections **144** have the same width dimension as the transmissive track sections **142**. The resolution of the code wheel **104** is a function of the width dimensions (as indicated by the span “x”) of the track sections **140** and **142**. In one embodiment, the width dimensions of the non-transmissive track sections **144** are a function of the amount of area required to produce a detectable gap between consecutive, transmitted light pulses. The radial, or height, dimensions (as indicated by the span “y”) of the transmissive and non-transmissive track sections **140** and **142** are a function of the amount of area required to generate a sufficient amount of photocurrent (e.g., the more photocurrent that is required, the larger the area required and hence the larger “y” needs to be since area equals “x” times “y”). Typically, the “y” dimension is made substantially larger than the height of the photodiodes **132**.

FIG. 9 depicts a schematic layout of one embodiment of a photosensor array **150** relative to the code wheel track **140**. The photosensor array **150** is also referred to as a photodiode array. A representation of the code wheel track **140** is overlaid with the photosensor array **150** to depict exemplary dimensions of the individual photosensor array elements (i.e., photodiodes **132**) with respect to the sections of the code wheel track **140**. Although the photodiode array **150** corresponds to a circular code wheel track **140**, other embodiments may implement a photosensor array **150** arranged to align with a linear track of a linear code strip.

The illustrated photodiode array **150** includes several individual photodiodes, including an A-signal photodiode **152** to generate an A signal, a B-signal photodiode **154** to generate a B signal, an A/-signal photodiode **156** to generate an A/-signal, and a B/-signal photodiode **158** to generate a B/-signal. For clarification, “A/” is read as “A bar” and “B/” is read as “B bar.” This designation of the position photodiodes **152**, **154**, **156**, and **158** and the corresponding electrical signals that are generated by the position photodiodes **152**, **154**, **156**, and **158** is well-known in the art. The circumferential dimensions (also referred to as the width dimensions, indicated by the span “w”) of the position photodiodes **152**, **154**, **156**, and **158** are related to the width dimensions of the position track

sections **142** and **144** of the corresponding code wheel track **140**. In the embodiment of FIG. 9, each position photodiode **152**, **154**, **156**, and **158** has a width that is one half the width of the transmissive and non-transmissive track sections **142** and **144** of the corresponding position track **140** (i.e., “w” equals “x/2”). Other embodiments of the photosensor array **150** may include other photosensors **132**, as are known in the art.

FIG. 10 depicts a schematic flow chart diagram of one embodiment of a method **170** for assembling the transmissive optical encoder system **50** of FIG. 2. Although specific reference is made to the transmissive optical encoding system **50** of FIG. 2, some embodiments of the method **170** may be implemented in conjunction with other optical encoding systems.

At block **172**, a detector **64** is mounted to a motor shaft **16**. As explained above, the detector **64** includes an aperture for a rotary shaft **16** to extend through the aperture of the detector **64**. The detector **64** is also mounted to receive light from an emitter **60**, which may be mounted after the detector **64** is mounted to the motor shaft **16**. At block **174**, a coding element such as a code wheel **54** (or the code wheel **104**) is mounted to the rotary shaft **16**. Upon rotation of the rotary shaft **16**, the code wheel **54** rotates and, hence, modulates the light signal incident at the detector **64**. In this way, the detector **64** detects the modulated light signal from the emitter **60** through the code wheel **54** during operation of the transmissive optical encoder system **50**.

At block **176**, an emitter **60** is provided. The emitter **60** is configured to generate a light signal. One example of an emitter **60** is a LED, which may be coupled to a collimating lens **62**, although other types of light sources may be implemented. In one embodiment, the emitter **60** is mounting to a housing or other structure to hold the emitter **60**. The depicted method **170** then ends.

Although the operations of the illustrated method **170** are shown and described in a particular, it should be noted that some embodiments of the method **170** implement the operations in another order. For example, some embodiments may implement multiple operations at substantially the same time, for example, by mounting a pre-assemble circuit to the motor shaft **16**.

FIG. 11 depicts a schematic flow chart diagram of one embodiment of a method **180** for making a detector **64** for the optical encoder of FIG. 2. Although specific reference is made to the optical encoder of FIG. 2, some embodiments of the method **180** may be implemented in conjunction with other optical encoders.

At block **182**, an aperture is formed through a substrate **66**. At block **184**, the photosensor array **68** is mounted on the substrate **66**. As used herein, the term mounting may refer to joining two structures, but is not necessary limited to joining or coupling separate structures together. Mounting also may include fabricating one structure from another structure. In one embodiment, the aperture and the photosensor array **68** are formed in the substrate **66** during wafer fabrication for an IC or IC package. By forming the aperture during wafer fabrication, the location of the photosensor array **68** relative to the aperture can be precisely dimensioned and positioned on the substrate **66**. Hence, direct mounting such a substrate **66** to the rotary shaft **16** can reduce tolerance stack-up. Since radial and tangential mismatch can affect the performance of the detector **64** in a small optical radius system, precise alignment of the photosensor array **68** relative to the rotary shaft **16** and, hence, the code wheel **54** is beneficial. Such precise

positioning also may enable increased encoder resolution because the photodiode tracks may be packed closely together.

At block **186**, the substrate **66** is mounted within a package. The package has an aperture corresponding to the aperture in the substrate **66**. Thus, the apertures of the substrate **66** and the package align to allow the rotary shaft **16** to extend through the detector **64**. It should be noted, however, that some embodiments of the detector **64** may be implemented without the use of a separate detector package. In fact, the detector **64** may be implemented using a variety of technology. An exemplary implementation for the detector **64** includes, but is not limited to, IC dice with normal wire bonding & encapsulation to protect the wire bonds. Another exemplary implementation for the detector **64** includes a flip chip with underfill to protect the ball bond. Another exemplary implementation for the detector **64** includes a chip-scale-package (CSP) or any other IC packaging. Other types of detectors also may be implemented.

At block **188**, the package is mounted to a flexible circuit **56**. At block **190**, an emitter **60** is also mounted to the flexible circuit **56**. In one embodiment, the emitter **60** is mounted to the flexible circuit **56** in a position to direct a light signal from the emitter **60** toward the photosensor array **66** of the detector **64**. Alternatively, the flexible circuit **56** may be arranged in another manner to direct the light signal from the emitter **60** toward the photosensor array **66** of the detector **64**. The depicted method **180** then ends.

FIG. **12** depicts a schematic block diagram of another embodiment of the transmissive optical encoding system **50** of FIG. **2**. In contrast to the transmissive optical encoding system **50** of FIG. **2**, the illustrated transmissive optical encoding system **50** shown in FIG. **12** includes an integrated circuit (IC) **192** with an integrated photosensor array. In this way, the photosensor array is integrated into one chip **192** with the circuitry. Accordingly, the bare chip **192** can be die attached and wire bonded onto the flexible cable **56** (or another substrate). In one embodiment, the chip **192** has an axial through hole in order to be mounted on the motor shaft **16**. In some implementations, this embodiment takes up a relatively small area of silicon, so it is feasible to mount the transmissive optical encoding system **50** on a small motor **18**. Additionally, similar to the detector **64** described above, the chip **192** may be square, square with chamfered corners, round, or another shape conducive to mounting on a particular motor **18**. Other embodiments may use other packaging such as chip scale packaging (CSP), quad flat no-lead (QFN), or another type of transparent package. In all embodiments, the packages include an axial through hole in order to mount the transmissive optical encoder **50** on the motor shaft **16**.

It should be noted that various forms of the optical encoder described herein may be implemented in several types of applications. For example, some embodiments of the optical encoder may implement an incremental encoder for two or three channels, or another number of channels. Other embodiments of the optical encoder may implement a commutation encoder with six channels, or another number of channels. Other embodiments of the optical encoder may implement a pseudo absolute encoder. Other embodiments of the optical encoder may implement an absolute encoder. Other embodiments of the optical encoder may implement other types of encoders.

Additionally, the various embodiments of the optical encoder may present one or more benefits. For example, some embodiments facilitate the implementation of a relatively small form factor to fit small rotary systems. Miniaturization may be further applicable with the advancement of smaller

transistor sizes in semiconductors. As another example, some embodiments enable a transmissive system for high frequency applications, without sacrificing the overall size of the transmissive optical encoder. As another example, some embodiments reduce or eliminate positional errors resulting from eccentricity. As another example, some embodiments enable simplicity in top-down assembly of a transmissive optical encoder. Other embodiments may provide other uses and benefits.

Although the operations of the method(s) herein are shown and described in a particular order, the order of the operations of each method may be altered so that certain operations may be performed in an inverse order or so that certain operations may be performed, at least in part, concurrently with other operations. In another embodiment, instructions or sub-operations of distinct operations may be implemented in an intermittent and/or alternating manner.

Although specific embodiments of the invention have been described and illustrated, the invention is not to be limited to the specific forms or arrangements of parts so described and illustrated. The scope of the invention is to be defined by the claims appended hereto and their equivalents.

What is claimed is:

1. An apparatus comprising:

a detector of a transmissive optical encoder, the detector comprising:

a circuit substrate comprising an aperture through the circuit substrate, the aperture to receive a rotary shaft of a motor; and

a photosensor array coupled directly to a surface of the circuit substrate, the photosensor array located on the circuit substrate at a position to receive a modulated light signal from an emitter through a coding element coupled to the rotary shaft.

2. The apparatus of claim 1, the detector further comprising a package to substantially enclose the photosensor array and the circuit substrate, wherein the package comprises an aperture through the package, wherein the apertures through the circuit substrate and the package are aligned to receive the rotary shaft of a motor.

3. The apparatus of claim 2, wherein the detector comprises a substantially rectangular package.

4. The apparatus of claim 3, wherein the substantially rectangular package comprises a chamfered corner.

5. The apparatus of claim 2, wherein the detector comprises a substantially cylindrical package.

6. The apparatus of claim 2, wherein the package further comprises a transmissive window, wherein the transmissive window is aligned with the photosensor array.

7. The apparatus of claim 2, wherein the package further comprises a cutaway window, wherein the cutaway window is aligned with the photosensor array, wherein the cutaway window has no structure to modify a path of a light signal from the code wheel to the photosensor array.

8. The apparatus of claim 7, wherein a top surface of the photosensor array is flush with a top surface of the package.

9. The apparatus of claim 7, wherein at least a portion of the photosensor array extends out of the package.

10. The apparatus of claim 1, wherein the aperture through the circuit substrate is approximately centered on a surface of the circuit substrate.

11. The apparatus of claim 1, wherein the aperture through the circuit substrate is off-center on a surface of the circuit substrate.

12. The apparatus of claim 1, wherein the photosensor array circumscribes the aperture through the circuit substrate on the surface of the circuit substrate.

11

13. The apparatus of claim **1**, wherein the aperture through the circuit substrate continues through an entire thickness of the detector.

14. The apparatus of claim **1**, wherein the photosensor array comprises a circular photosensor array. 5

15. The apparatus of claim **14**, the detector further comprising a package to at least partially enclose the circuit substrate, wherein the package comprises an aperture through the package to receive the rotary shaft of the motor.

16. The apparatus of claim **15**, wherein the package comprises a circular window aligned with the circular photosensor array. 10

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12